

RISKY CHOICE AS A FUNCTION OF AMOUNT AND VARIANCE IN FOOD SUPPLY

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In Experiment 1, 4 rats earned their daily food ration by choosing on a trials basis between a "risky" and a "riskless" lever. The risky lever produced either 15 45-mg food pellets or no pellets, and on average provided five pellets per choice. The riskless lever always produced three pellets. Across conditions, the number of trials per session was varied. Body weight and choice of the risky lever decreased as the number of trials per session decreased, even though body weight could only be defended by increased choice of the risky lever. In Experiment 2, trials per session were fixed, but the number of pellets delivered by the risky and riskless levers was either at the same level as in Experiment 1 or tripled from those levels. Now choice of the risky lever was inversely related to the size of reinforcement and to body weight. The results of these experiments show that risk aversion covaries with the amount of food available in a session and the daily variance in the amount of food earned.

Key words: risky choice, risk aversion, repeated gambles, optimal foraging, reinforcement variance, reinforcement amount, choice, bar press, rats

Kahneman and Tversky (1979) developed prospect theory by evaluating human preferences between different outcomes presented in 14 separate problems. They used the following example to illustrate their method (p. 264):

Which would you prefer (all amounts in Israeli pounds)? A. 50% chance to win 1,000, 50% chance to win nothing; B. 450 for sure.

They found that most subjects chose Outcome B, a result demonstrating the primacy of *risk aversion* over utility maximization in human risky choice.

One reason why humans are averse to risk is that the value they assign to a good is a

monotonically increasing, negatively accelerated function of its size (Kahneman & Tversky, 1979). Two predictions follow from this hypothetical value function: (a) The relative value of two goods that differ in size (but not kind) will be less than their relative size; and (b) at the limit, these goods will have essentially the same value. Combined, these predictions suggest human risk aversion should increase as the sizes of the risky and riskless alternatives are proportionally increased.

Although studies that have manipulated reinforcement level are generally consistent with this prediction (e.g., Silberberg, Murray, Christensen, & Asano, 1988), related non-human-based tests have produced equivocal results: In some studies, increasing reinforcement in risky choice led to the predicted increase in preference for the riskless alternative (Barnard & Brown, 1985; Caraco, Martinale, & Whittam, 1980; Hamm & Shettleworth, 1987; Mazur, 1988); but in others, risk aversion seemed largely insensitive to changes in within-session reinforcement (Battalio, Kagel, & MacDonald, 1985; Kagel, MacDonald, Battalio, White, & Green, 1986).

The inconclusive results of these nonhuman-based tests of risky choice might be due to the fact that a subject's daily food consumption was largely independent of the frequency with which the risky or riskless alter-

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native was chosen. This expectation comes from two features shared by all experimental designs. First, the expected value of the riskless and risky alternatives was the same. Second, in all studies there were many choices per day, ensuring that aggregate reinforcement obtained from the risky alternative closely approximated its expected value.

These arrangements surely differ from those used to study risky choice in humans. In the Kahneman and Tversky (1979) example presented above, all choices are unique and a premium is paid for the assumption of risk. In their situation, either of these characteristics is sufficient to ensure that earnings vary substantially with choice.

The present experiment is the first attempt to evaluate the effects of reinforcement level on risky choice in nonhumans under conditions in which choice clearly affects the amount of food earned. Toward this end, rats earned their daily food ration during sessions in which the risky lever provided 15 food pellets with $p = .33$ or no pellets with $p = .67$, and the riskless lever provided three pellets with $p = 1.0$. Across conditions, the number of trials per session was manipulated. The primary goal of this exercise was to determine whether the covariation between risk aversion and reinforcement level predicted by Kahneman and Tversky's (1979) hypothetical value function and found in some nonhuman-based studies of risky choice (e.g., Caraco *et al.*, 1980) obtains when choice affects total food earned.

EXPERIMENT 1

Method

Subjects. Four experimentally naive male Sprague-Dawley albino rats (Subjects 1, 2, 3, and 4), weighing between 400 and 420 g at their free-feeding weights at the start of the experiment, served as subjects. They were housed individually. Water was available continuously in the animals' cages and experimental chambers. They had no access to food between sessions.

Apparatus. Two identical chambers (30 cm by 25 cm by 29 cm) with grid floors (Coulbourn Instruments Model E10-10F) housed in larger sound-insulated boxes served as the experimental spaces. Two 3.5-cm-wide levers positioned 19 cm apart and 6.5 cm above the

grid floor were located on the front wall of each chamber. Each lever required a force of 0.25 N to operate. A 28-V stimulus light was located 4 cm above each lever and 25 cm above a food tray centered between the levers and 2 cm above the floor. A water bottle was mounted on one of the Plexiglas side walls.

Procedure. Each session consisted of 12 forced-choice trials followed by a number of free-choice trials that varied across experimental conditions. During each forced-choice trial, one lever was selected as correct, a circumstance signaled by illuminating the light above that lever during that trial. Selection of the signaled lever was random with the constraint that, during the 12 forced trials, each lever would be signaled six times. Responding to the unsignaled lever had no scheduled consequences, whereas selection of the signaled lever turned off the lever light, turned on the light over the food cup, and initiated the delivery of food pellets (one pellet per second) according to the contingencies in force during the free-choice trials that followed. In the event that no pellets were scheduled to be delivered, the food-cup light was extinguished after 1 s. Following delivery of the last pellet, the hopper light was extinguished and the houselight was turned on, signaling a 60-s intertrial interval (ITI). At the end of the ITI, the signaled lever for the next forced-choice trial was selected. Following 12 forced-choice trials, the free-choice regime was begun. During these trials, the lights above both levers were illuminated. In all other ways, the procedure was the same as during forced-choice trials.

During Phases 1, 3, 5, and 7, the left lever was designated as "risky" and the right lever was "riskless," and during Phases 2, 4, 6, and 8 these designations were reversed. In all phases, selection of the risky lever produced 15 45-mg food pellets with $p = .33$ or no food pellets with $p = .67$, and each choice of the riskless lever produced three 45-mg pellets with $p = 1.0$.

Reinforcement level was manipulated by varying the number of free-choice trials per session (see Table 1). In Phases 1 and 2, all rats were given 138 free-choice trials. In Phases 3 and 4, the number of free-choice trials for each subject equaled one fifth of the number of pellets they earned during the last five sessions of Phases 1 and 2. This value was selected because it ensured that animals could maintain

Table 1

Number of free-choice trials per session and, in parentheses, mean number of free-choice trials with a response during the last five sessions of each condition in Experiment 1.

Subject	Condition							
	1	2	3	4	5	6	7	8
1	138 (95)	138 (97)	75 (75)	75 (71)	41 (41)	41 (41)	138 (138)	138 (109)
2	138 (83)	138 (97)	73 (73)	73 (73)	51 (51)	51 (51)	138 (120)	138 (104)
3	138 (96)	138 (93)	80 (80)	80 (80)	50 (50)	50 (50)	138 (138)	138 (87)
4	138 (88)	138 (99)	86 (86)	86 (86)	64 (64)	64 (64)	138 (105)	138 (98)

approximately the same food intake in Phases 3 and 4 as they obtained in Phases 1 and 2 only by choosing the risky alternative exclusively. In Phases 5 and 6, the number of free-choice trials was arbitrarily set equal to two thirds of the number of pellets earned during the last five sessions of Phases 3 and 4. Finally, Phases 7 and 8 were a return to the Phase 1 and Phase 2 baseline conditions.

Daily sessions ended after the free-choice trial limit was reached or after 30 min without a response. Experimental phases ended when the proportion of risky lever choices in each session of the last five sessions was within 6% of the mean and at least 20 sessions had been completed. In the event that this stability criterion was not met within 50 sessions, the phase was ended after 50 sessions. Unless noted otherwise, all data are based on the last five sessions of a given phase.

Results

Figure 1 presents each subject's body weight (in grams) on the last session of a given phase of the experiment as a function of the number of trials in that phase. Body weights during the initial exposure to a given reinforcement level (odd-numbered phases) are represented by open symbols, and body weights during the reversal conditions (even-numbered phases) are represented by filled symbols. Triangles are used to represent the redetermined body weights during the 138-trial conditions. These data show that as total reinforcement was reduced by decreasing the number of trials per session, animals' body weights decreased.

Table 1 also presents the mean number of free-choice trials with a response during the last five sessions of each condition for each subject. Except for the highest reinforcement condition, all subjects used virtually all available free-choice trials. No data were collected

on how long it took animals to consume pellets or on the number of pellets that remained uneaten after each session.

Figure 2 presents the proportion of choice of the risky lever, defined as the frequency of risky-lever choices divided by all choices, during the last five sessions for each rat in each phase of the experiment. The solid curve in each panel presents performances when the left key was risky, and the dashed curve is a redetermination at the same reinforcement level with the right key being risky. These data demonstrate a clear correlation between reinforcement level and willingness to choose the risky alternative.

Discussion

We found that rats came to prefer the riskless alternative as reinforcement level was reduced, despite the fact that this preference lowered their daily food consumption. This finding is the opposite of the predictions of Kahneman and Tversky's (1979) hypothetical value functions and the results of several nonhuman-based experiments (Caraco et al., 1980; Hamm & Shettleworth, 1987, Experiment 1; Mazur, 1988). Moreover, this finding is difficult to explain in terms of extant choice models. For example, risk-sensitive foraging models predict that foragers should be averse to risk when food availability from riskless alternatives is sufficient to meet caloric needs, but should be risk seeking when riskless alternatives result in an energy deficit (Caraco et al., 1980). Yet the results we obtained are exactly opposed to this prediction.

One way to reconcile the current work with prior research on risky choice is to attribute our results to some variable other than reinforcement level. Toward this end, notice that in reducing reinforcement level by reducing trials per session we also increased reinforce-

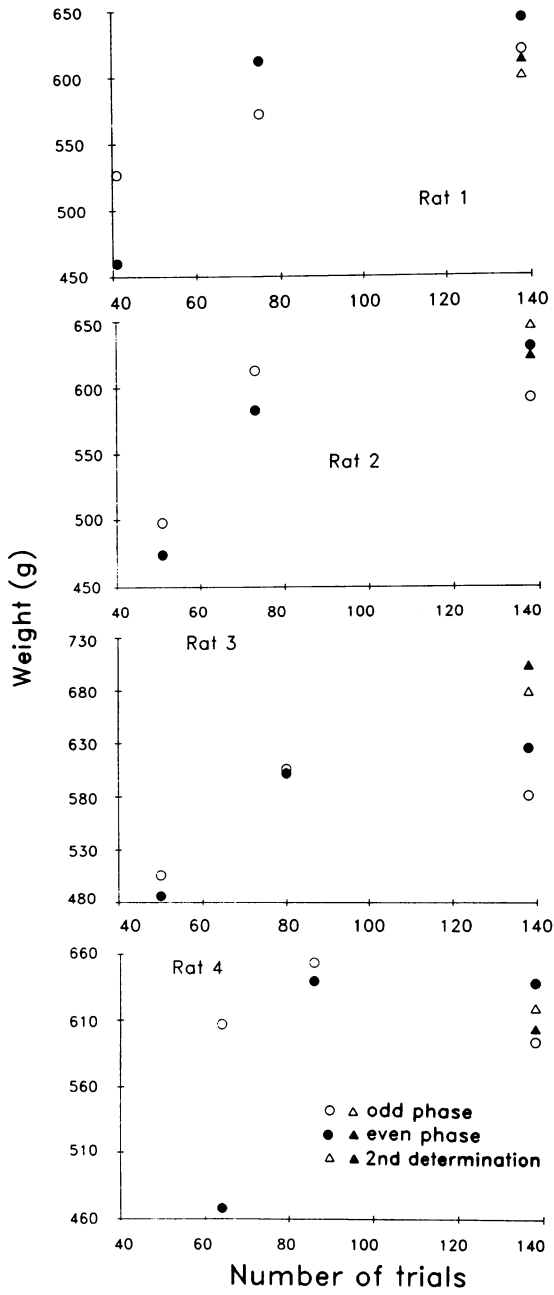


Fig. 1. Body weight in grams as a function of the number of trials per session for each rat in each phase of the experiment. See text for details.

ment variance. That is, the fewer the number of trials per day, the greater the variability in daily food consumption given that some portion of a rat's choices are to the risky alternative. Thus, our results show that rats become

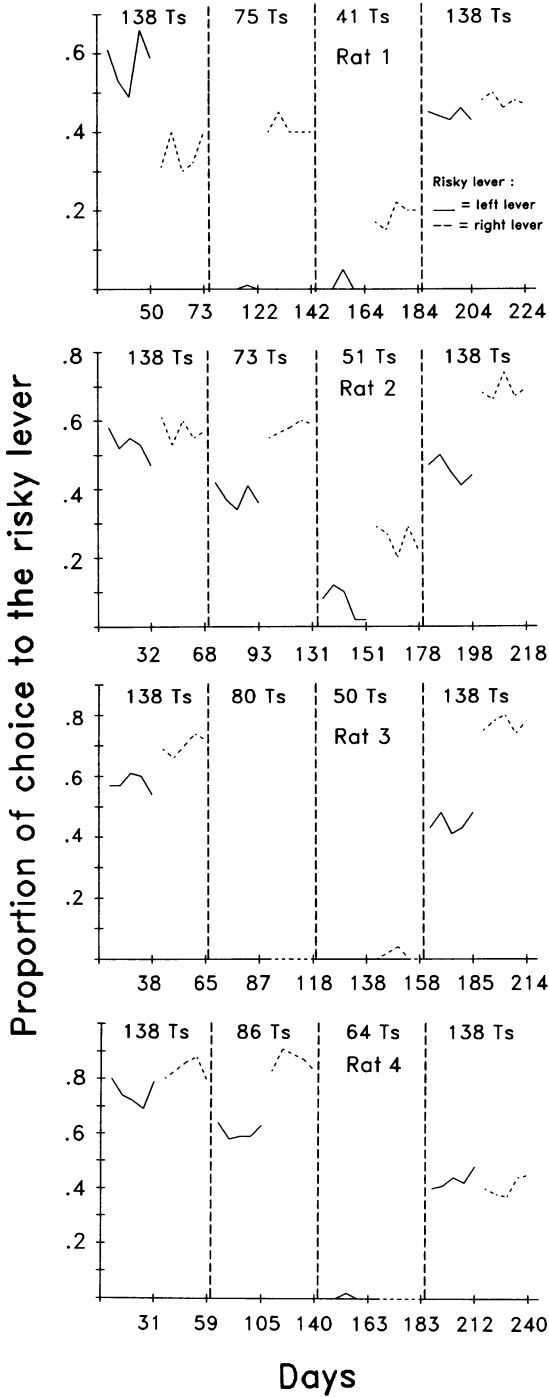


Fig. 2. Relative frequency of risky-lever choices as a function of sessions. The numbers of trials per session are presented in the top of each panel. See text for other details.

Table 2
Order of conditions in Experiment 2.

Subject	Condition					
	1	2	3	4	5	6
5	3 vs. 0 or 15	9 vs. 0 or 45	3 vs. 0 or 15			
6	3 vs. 0 or 15	9 vs. 0 or 45	3 vs. 0 or 15			
7	9 vs. 0 or 45	3 vs. 0 or 15	9 vs. 0 or 45			
8	9 vs. 0 or 45	3 vs. 0 or 15	9 vs. 0 or 45			

more averse to risk as the day-to-day variance in the number of reinforcers earned increases.

Attributing our findings to reinforcement variance can explain why our results differ from those of others. However, this does little to reconcile our findings with the probable predictions of risk-sensitive foraging models. The problem is that these models suggest that nonhumans should take greater risks when their food supply is made more variable. Yet the opposite result obtained even though reducing trials per session made food more variable and lowered total intake.

We have reconciled this study's findings with prior work by suggesting that there are two consequences of reducing trials per session. One consequence is that the reinforcement level is reduced, causing subjects to become more risk seeking; the other consequence is that reinforcement variance is increased, producing greater risk aversion. If this two-process account of risky choice is correct, we should be able to reproduce the conventional finding that risky choice decreases with increasing reinforcement level if we vary reinforcement level by changing reinforcer sizes and keep trials per session constant. Experiment 2 makes this test.

EXPERIMENT 2

Method

Subjects. Four male Sprague-Dawley albino rats (Subjects 5, 6, 7, and 8) that had been used in a prior risky-choice experiment served as subjects. They were housed individually. Water was continuously available in the animals' cages and experimental chambers. They had no access to food between sessions.

Apparatus. The apparatus was the same as in the prior experiment.

Procedure. In the low-reinforcement conditions, choice of the risky lever produced either

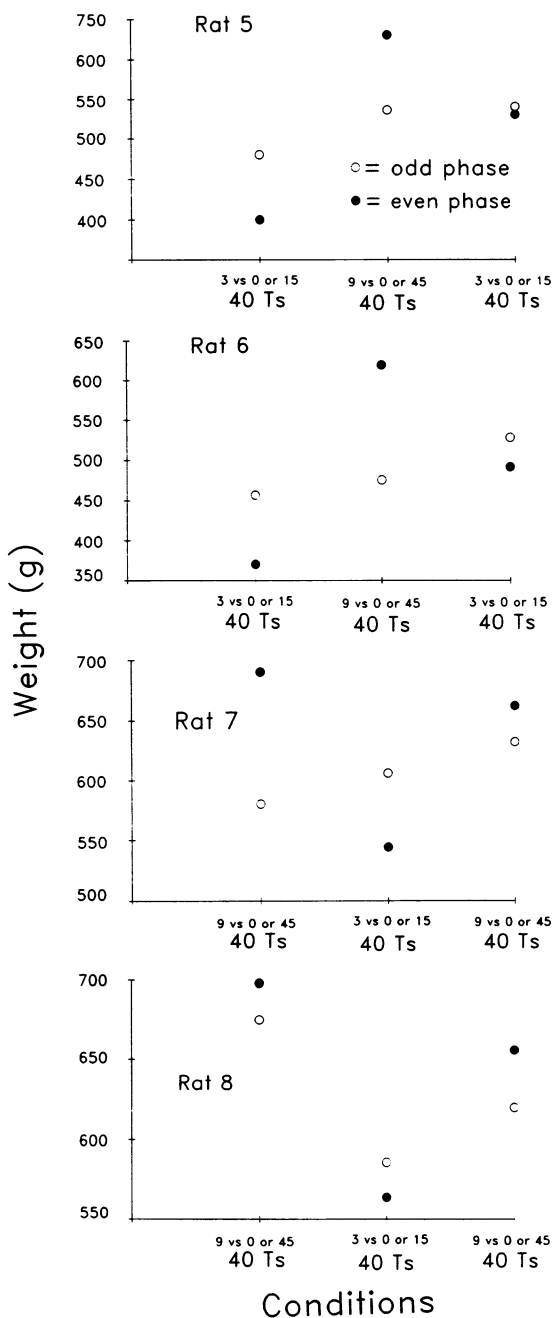


Fig. 3. Body weight in grams as a function of reinforcement level for each rat in each phase of the experiment.

no pellet ($p = .67$) or 15 pellets ($p = .33$), whereas choice of the riskless lever produced three pellets with $p = 1.0$. In the high-reinforcement conditions, all amounts were tripled. That is, choice of the risky lever produced

Proportion of choice to the risky lever

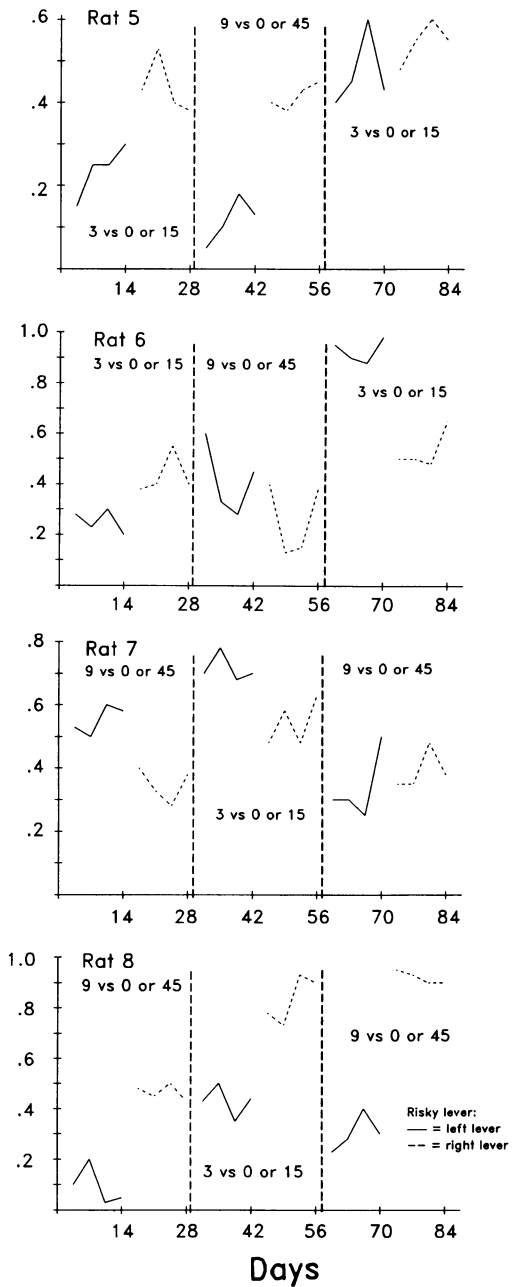


Fig. 4. Relative frequency of risky-lever choices as a function of sessions. The numbers of pellets delivered in choice are presented in each panel.

no pellets for two thirds of those choices and 45 pellets for one third of those choices. Riskless-lever selection always produced nine pellets. All sessions ended after 40 free-choice trials. The order of conditions is presented in

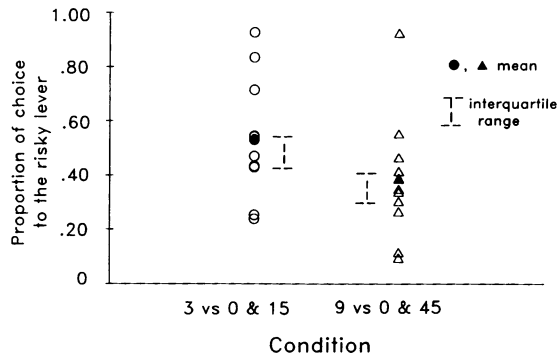


Fig. 5. Proportion of choice to the risky lever as a function of reinforcement level. See text for details.

Table 2. All other features of the procedure are the same as in the prior experiment.

Results and Discussion

Figure 3 presents each subject's body weight (in grams) on the last day of every condition of Experiment 2. In general, weights decreased when reinforcer amounts were small and increased when they were high.

Figure 4 presents the proportion of choice of the risky lever as a function of sessions for each subject. Vertical dashed lines define panels in which reinforcement level has been changed. Although there was often considerable variability within a condition when lever-outcome assignments were reversed, there was a tendency for risky choice to increase when reinforcement level was reduced.

This conclusion is easier to see in Figure 5, which presents the mean result of each function presented in the prior figure segregated according to reinforcement level. As is apparent, the preference for the risky lever was greater when reinforcement was lower, and there is no overlap in the interquartile ranges between the two reinforcement conditions. These results are consistent with foraging models such as that of Caraco *et al.* (1980) in showing that reductions in food consumption lead to increased risk-seeking behavior.

GENERAL DISCUSSION

In these two experiments, rats chose between risky and certain outcomes. In both studies, the risky alternative had the higher expected value. We interpret risk-sensitive foraging models as predicting that when total re-

inforcement was reduced in Experiment 2, or when the amount of food earned in a session became more variable in Experiment 1, rats would respond by choosing the riskier, higher-expected-value alternative more frequently. These expectations were fulfilled with respect to reinforcement level but not with respect to reinforcement variance. Indeed, the aversion to increased variance in food consumption in Experiment 1 was so great that it prevailed over the risk-taking effects of the attendant decrease in total reinforcement.

One reason aversion to variance in food consumption has not appeared in other nonhuman-based tests of risky choice may be because food consumption in these other studies did not vary either from session to session or as a function of choice (see Introduction). However, there is precedent for the present study's outcomes in a study by Keren and Wagenaar (1987). In their report, humans were given a single choice between a nearly riskless alternative (win 100 Dutch guilders with $p = .99$) and a risky alternative with a higher expected value (win 250 Dutch guilders with $p = .5$). In another part of their study, the gamble was repeated 10 times in choice between 10 guilders with $p = .99$ and 25 guilders with $p = .5$. They found that most subjects chose the riskless alternative when the gamble was unique, but preferred the risky choice when the gamble was repeated (also see Silberberg et al., 1988). These results support the demonstration in the present report that the greater the number of risky choices per session, the greater the preference for the risky alternative.

In comparing the present report to prior studies of nonhuman risky choice, we note a difference in the characterization of risk. In prior studies, risk is defined as a local fluctuation in the probability or size of an individual reward that does not translate into substantial fluctuations in daily reward levels. In the present report, on the other hand, changes occur both in terms of the size or probability of an individual reward and in the total reward levels.

Although it is difficult to claim that one characterization of risk is superior to the other, we do see two advantages to ours. First, it is the characterization used in the literature on human risky choice—a literature that has served as much of the impetus for doing nonhuman-based tests of risky choice. Second, our

characterization of risk seems to us better designed to test nonhuman models of risky choice. For example, Caraco et al.'s (1980) risk-sensitive foraging model assumes that subjects will increase their preference for a risky alternative when choice of the riskless alternative results in an energy debit. Yet, tests of this model pay no premium for increases in the choice of the risky alternative. As a consequence, these studies argue that subjects increase their choice of a risky alternative even though it is unlikely that assumption of risk will alter their food intake.

In our study, unlike prior tests of Caraco et al.'s (1980) model, subjects could defend against an energy debit by increasing the frequency with which they chose the risky alternative. Consistent with the predictions of this model, they assumed more risk when food availability was restricted by reducing reinforcer amounts. However, when food availability was reduced by reducing the number of trials per session, rats became more averse to risk, even though such a strategy resulted in a loss of weight.

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